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Mental Illness in Film and TV: A Content Analysis of Steven Universe Future

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Abstract

Steven Universe, a children's cartoon show that piloted in May of 2013, is a science-fantasy series written by Rebecca Sugar that follows the adventures of Steven Universe, a half-human half-gem (i.e. alien) who protects Earth from intergalactic threats alongside his guardians, the Crystal Gems. Throughout each successive season, Steven encounters increasingly dangerous villains, learns to navigate the gem powers passed to him from his mother, and is subsequently villainized for her crimes. The purpose of this study was to conduct a film review of *Steven Universe* to investigate the accuracy of the portrayal of three mental illnesses (i.e. major depressive disorder, generalized anxiety disorder, and post-traumatic stress disorder), in addition to the presence of mental illness stigma. Episodes were chosen solely from the finale season *Steven Universe Future*, as it depicts the culmination of the trauma Steven endures in prior seasons. Moreover, the criteria for measuring the frequency of these mental illnesses was based on the 2013 Diagnostic and Statistical Manual of Mental Disorders. To determine the presence of stigma, components of the Mental Illness Stigma Framework were observed, namely the stigmatization mechanisms used against individuals with mental illnesses. The results found that a majority of episodes had relatively accurate depictions of the three investigated mental illnessses and were devoid of mental illness stigma. These findings suggest that it is feasible for television and film outlets to portray constructive depictions of mentally ill characters and that, among modern shows, Steven Universe sets a replicable standard for achieving this.

Keywords: Major depressive disorder, Generalized anxiety disorder, Post-traumatic stress disorder, Stigma

1. Introduction

In a study conducted by the USC Annenberg Inclusion Initiative and American Foundation for Suicide Prevention on the top movies and TV series from the 2016-2017 film season, the predominant portrayal of characters with mental illnesses was found to be negative. Common treatment of these characters included disparagement and the trivialization of their experiences via humor (Smith, et al., 2019). Stigmatization is a norm in the depiction of mental conditions in popular television, which creates a narrative that discourages help-seeking and discussions of mental wellness among general audiences - children and adults alike.

Thus far, the scholarly literature surrounding *Steven Universe* has mainly appraised the show's queer representation, focusing on its inclusion of diverse, LGBTQIA+ characters (Dunn, 2016; Moore, 2019). That is to say, there have not yet been studies published that focus on the show's depiction of mental illness. However, tangential studies have already measured the presence of mental illness in other, similar children's shows and films. For instance, a 2004 content analysis of animated films by The Walt Disney Company (TWDC) published in the Canadian Journal of Psychiatry found that, among the 34 selected feature films, most carried demeaning references to characters with mental illnesses (Lawson & Fouts, 2004). The most common verbal references were the words "crazy," "mad," and "nutty," all of which were "employed to segregate, alienate, and denote the inferior status of the character(s) to which

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they referred" (Lawson & Fouts, 2004). Based on this data, authors Andrea Lawson and Gregory Fouts expressed concern that children's exposure to such a dramatized, dehumanizing image of mental illness through TWDC films would cause them to conceive "[an] unrealistic and stereotypic view of individuals with a mental illness in society" (Lawson & Fouts, 2004). A similar study conducted in the British Journal of Psychiatry sampled a full week of children's television to observe the presence and means by which mental illnesses were depicted. The analysis found that 59 of the 128 episodes observed contained one or more references to mental illness, with cartoons having the most references among all the episode types (Wilson, et al., 2000). Additionally, characters who were most consistently referenced with this language were labeled as mentally ill (Wilson, et al., 2000). Among the 6 characters deemed to be mentally ill, none displayed redeemable qualities; they instead engaged in irrational behaviors and served as sources of entertainment for other characters (Wilson, et al., 2000). The study was unable to find "any understanding of the suffering that mental illness involves" and suggested that the "generic nature of the illnesses portrayed" and "the lack of specificity of symptoms or diagnosis" invited young audiences to not only make falsified generalizations about mental illness, but also to apply said assumptions to all mentally ill individuals within the real-life context. Since existing children's entertainment already lacks nuanced portrayals of mental illness, the primary objective of the study was to confirm the validity of the hypothesis that *Steven Universe* diverges positively the norm of children's TV.

Key to analyzing the prevalence and accuracy of mental illnesses' portrayal in *Steven Universe* is an understanding of the defining characteristics of each selected condition. According to the National Library of Medicine, major depressive disorder (MDD) is a condition characterized by a combination of "[a] persistently low or depressed mood …[,]decreased interest in pleasurable activities, feelings of guilt or worthlessness, [a] lack of energy, poor concentration, appetite changes, psychomotor retardation or agitation, sleep disturbances, [and] suicidal thoughts" (Bains & Abdijadid, 2022). In accordance with DSM-5, an individual must demonstrate 5 or more of the aforementioned symptoms and be socially or occupationally impaired by their depressed mood within a 2-week period to be medically diagnosed with MDD (Bains & Abdijadid, 2022). Similarly, generalized anxiety disorder (GAD) is a mood disorder that causes "persistent, excessive, and unrealistic worry about everyday things," such as one's financial well-being, health, and familial stability (Munir & Takov, 2022). A wide range of symptoms can manifest as a result of GAD, including restlessness, fatigue, irritability, sleep disturbance, and muscle tension (Munir & Takov, 2022). An individual can be officially diagnosed with GAD once they exhibit these symptoms frequently within a 6-month period (Munir & Takov, 2022). Finally, post-traumatic stress disorder (PTSD) is a psychiatric illness that, unlike MDD and GAD, *must* be triggered by exposure to an actual traumatic experience, such as a significant injury or sexual assault (Mann & Marwaha, 2022). Common symptoms of PTSD include "re-experiencing the [original] traumatic event, intrusive thoughts, nightmares, flashbacks, dissociation…[,] and intense negative emotional…and physiological reaction[s] [upon] being exposed to the traumatic reminder" (Mann & Marwaha, 2022). Alongside these symptoms, individuals with PTSD may also have difficulty concentrating, become more irritable, and exhibit hypervigilance (Mann & Marwaha, 2022). Fortunately, all of these mental conditions can be effectively remedied with prescription medication or psychotherapy, making help-seeking a critical component of mental illness recovery (Bains & Abdijadid, 2022; Mann & Marwaha, 2022; Munir & Takov, 2022). On the whole, the medical research surrounding each illness would provide a more in-depth understanding of Steven's symptoms, whether it be through his outward behaviors or dialogue.

The final component critical to this film review is mental illness stigma. As defined by the American Psychological Association, stigma is a "negative social attitude attached to a characteristic of an individual that may be regarded as a mental, physical, or social deficiency" (APA, n.d.). The MISF, developed by researchers Annie Fox, Valerie Earnshaw, Emily Taverna, and Dawne Vogt, proposes a holistic framework for understanding the way individuals experience societal stigmas surrounding mental illness, accounting for the perspective of both the stigmatized and the stigmatizer (Fox, et al., 2018). Within the MISF, the three most significant mechanisms used by stigmatizers (i.e. individuals without mental illness) in response to encounters with the stigmatized (i.e. individuals with mental illness) are stereotypes, prejudice, and discrimination (Fox, et al., 2018). The most common stereotypes used against the mentally ill include "dangerousness, rarity, responsibility, incompetence, weakness of character, and dependence" (Fox, et al., 2018). Prejudice, or "the emotional reaction or feelings that people have toward a group or member of a group," is also leveraged against the mentally ill, most frequently taking the form of anger, pity, and fear

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(Fox, et al., 2018). In the same way, discriminatory behaviors, such as "withholding help, avoidance, segregation, and coercion," serve as additional barriers to mentally ill individuals' recovery (Fox, et al., 2018). In other words, individuals struggling with mental illness face the potential of significant maltreatment from unaffected peers and family. Of even more importance is the fact that the treatment of the mentally ill by others markedly impacts their willingness to discuss their issues, seek outside guidance, and navigate their day-to-day life. Since mental illness stigma in television usually manifests through the language and actions of non-mentally-ill-characters (e.g. name-calling, bullying, ostracization) the perspective of the stigmatizer becomes crucial in the evaluation of stigma in *Steven Universe Future*.

2. Materials and Methods

Content analysis is a "research tool used to…quantify and analyze the presence, meanings, and relationships of such certain words, themes, or concepts" within a body of qualitative data (Columbia Public Health, n.d.). For the content analysis within this study, several salient episodes from *Steven Universe Future* were chosen and reviewed. The entirety of the finale season was rewatched to determine the episodes wherein Steven's emotional trauma responses were most prominent. Out of the 20 episodes in the season, the 7 episodes with the most cumulative frequencies of mental illness symptoms among all three disorders were selected for conceptual analyses. After completing the episode selection, each episode was re-watched for data collection, which entailed measuring the frequency of mental illness symptoms. Based on Steven's observed behaviors, symptoms were deemed "present" (P) or "not present" (NP). Separately, three 4-point scales were developed that measured the accuracy of the depiction of each mental illness based on the amount of DSM-5 diagnostic criteria they fulfilled, excluding time-based requirements since episodes were analyzed in isolation and several had muddled timelines. Once a symptom chart for a given mental illness was completed, the corresponding accuracy scale was employed to determine if the portrayal of said illness was very inaccurate, somewhat inaccurate, somewhat accurate, or very accurate. Differences in accuracy categories were evaluated based on the number of diagnostic criteria missing (ex. a somewhat accurate portrayal of PTSD is missing 1-2 criteria whereas a somewhat inaccurate portrayal misses 3-4). Clauses in each set of criteria regarding whether the illness could be better ascribed to a different disorder were also removed, as otherwise, only the presence of a singular mental illness would've been measured per episode. Furthermore, 3 results tables were created to organize each episode's accuracy determinations for each mental illness.

In another, separate results chart, the MISF, a framework with "terminology for understanding mechanisms of mental illness stigma" based on existing "prominent mental illness stigma theories, conceptualizations and definitions," (Fox, et al., 2018) was used to track mental illness stigma against Steven for each selected episode. If any of the three types of negative responses towards people with mental illness identified by the MISF (i.e. stereotypes, prejudice, discrimination) were observed through characters other than Steven in each episode, stigma was considered "present" (P).

3. Results

Tables 1 through 3 summarize the accuracy findings of each mental disorder for each selected episode. The general trend indicates that the majority of episodes demonstrated depictions that were somewhat accurate or very accurate for each mental illness (i.e. MDD, GAD, and PTSD). In regards to Table 4, which details the presence of stigma within each episode, most episodes were found to have an absence of all three stigmatization mechanisms. Across all 7 episodes, only 2 instances of stereotyping and 1 instance of prejudice were exhibited, with none of the instances overlapping within the same episode.

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Table 1: Accuracy chart of major depressive disorder portrayal per selected episode

Major Depressive Disorder				
Episode	Very Inaccurate	Somewhat Inaccurate	Somewhat Accurate	Very Accurate
Volleyball	0	1	0	0
Prickly Pair	0	0	1	0
In Dreams	0	0	1	0
Growing Pains	0	0	0	1
Fragments	0	0	0	1
Homeworld Bound	0	0	1	0
Everything's Fine	0	0	1	0
Total	0	1	4	2

Table 2: Accuracy chart of generalized anxiety disorder portrayal per selected episode

Generalized Anxiety Disorder				
Episode	Very Inaccurate	Somewhat Inaccurate	Somewhat Accurate	Very Accurate
Volleyball	0	0	0	1
Prickly Pair	0	0	0	1
In Dreams	0	0	0	1
Growing Pains	0	0	1	0
Fragments	0	0	0	1
Homeworld Bound	0	0	0	1
Everything's Fine	0	0	0	1
Total	0	0	1	6

Table 3: Accuracy chart of post-traumatic stress disorder portrayal per selected episode

Post-Traumatic Stress Disorder				
Episode	Very Inaccurate	Somewhat Inaccurate	Somewhat Accurate	Very Accurate
Volleyball	0	0	0	1
Prickly Pair	0	0	1	0
In Dreams	0	0	0	1
Growing Pains	0	0	0	1
Fragments	0	0	0	1
Homeworld Bound	0	0	0	1
Everything's Fine	0	0	0	1
Total	0	0	1	6

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Table 4: Presence of stigma per selected episode

Stigma Mechanism	Definition	Volleyball	Prickly Pair	In Dreams	Growing Pains	Fragments	Homeworld Bound	Everything's Fine
Stereotypes	"The core stereotypes associated with mental illness include dangerousness, rarity, responsibility, incompetence, weakness of character, and dependence" (Fox, et al., 2018).	NP	NP	P	NP	P	NP	NP
Prejudice	"The most common forms of prejudice toward PWMI are fear, pity, and anger" (Fox, et al., 2018).	P	NP	NP	NP	N	NP	NP
Discrimination	"There are four common types of discrimination directed towards PWMI…[:] withholding help, avoidance, segregation, and coercion" (Fox, et al., 2018).	NP	NP	NP	NP	NP	NP	NP

4. Discussion

To best understand how Steven's actions and behaviors correlate to his mental illness diagnoses, it's key to analyze his recurring symptoms across each disorder. Their respective portrayals will also be discussed at length, considering they meaningfully shape the audience's perception of Steven as an individual.

4.1 Guilt

Guilt is Steven's most prominent emotion across the episodes with somewhat or very accurate depictions for all three conditions. For example, in the episode "In Dreams," Steven discovers a newfound power that allows him to broadcast his dreams like movies onto electronic devices, such as his home TV. As such, he decides to collaborate with his friend Peridot to create a modified version of the new season of their favorite TV show, Camp Pining Hearts. For their plan to work out, Steven had to dream of an altered plot so that Peridot could view it broadcast on Steven's TV. Unfortunately, Steven ends up being plagued by several nightmares that distort the projected dreams. At the end of the episode, Steven is startled awake by a particularly disturbing nightmare and breaks down in tears. He tells Peridot "I don't think I know how to be a friend without something to fix!...I'm sorry I can't do this for you!" (Guignard et al., 2020, 7:49). The "something to fix" is a reference to the Camp Pining Hearts plot that he and Peridot were attempting to alter. This behavior was categorized as excessive guilt, a qualifying symptom of MDD (Bains & Abdijadid, 2022), in addition to a persistent negative emotional state, one of the markers of PTSD (Mann & Marwaha,

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2022). The portrayal of these symptoms adds depth to Steven's condition, veering away from the negative archetype of mentally ill characters established in previous media, such as the TWDC feature films explored in Andrea Lawson and Gregory Fouts' 2004 study. Considering that "inappropriate guilt becomes less normative with age" since children are better able to identify events' cause-effect relations as they mature, Steven's partial acknowledgment of the reason for his guilt is consistent with the emotional cognition of a depressed individual of his age (Pulcu et al., 2013). Still, Steven demonstrates a large magnitude of guilt, which reflects the idea that "direct personal involvement during [a] traumatic event is associated with greater guilt" and that it can produce "stronger perceived responsibility and sense of wrongdoing" (Kip et al., 2022). Overall, the inclusion of these symptoms provides for a more constructive understanding of MDD and PTSD, enabling viewers to be more cognizant how their symptoms are manifested.

4.2 Anger

Across the majority of episodes with somewhat or very accurate depictions of the investigated mental illnesses, anger was observed to be a recurring symptom. For instance, in the episode "Volleyball", Steven's mother's former servant Pink Pearl approaches him for help in healing a crack on her left eye. After failing to heal the crack with the power of his magical healing spit, he and Pearl, one of his adoptive gem guardians, accompany Pink Pearl to a coral reef to find other means of fixing her physical form. However, none of the resources available at the reef are able to mend Pink Pearl's crack either, which upsets Steven. While this is happening, Pink Pearl discusses the origins of her injury and reflects on her past relationship with Steven's mother, revealing that her damaged form was actually caused by unresolved emotional trauma from a tantrum thrown by Steven's mother in her youth. Visibly agitated by this new information, Steven yells "I can't deal with one more horrible thing she did, okay?" and creates fissures in his surroundings from his power-imbued scream (Guignard et al., 2019, 7:53). This behavior was classified under the symptoms of restlessness and irritability for GAD (Munir & Takov, 2022), and characterized as an angry outburst under PTSD (Mann & Marwaha, 2022). Steven's irritability is most likely an "abberant response to reward," a frustrated response in which "an individual continues to do an action in the expectation of a reward but does not actually receive that reward" (Vidal-Ribas & Stringaris, 2021). The "action," in this case, is searching for physical remedies to Pink Pearl's crack instead of confronting the breadth of her emotional abuse under his mother. Unable to see tangible results of his healing efforts, Steven becomes irate when the severity of his mother's wrongdoing towards Pink Pearl is fully unveiled, which causes him to lash out. When understood from the perspective of PTSD symptom criteria, his emotional response is aligns with the idea that "day-to-day exposure to emotionally distressing trauma cues may underlie the increased risk for infrequent (but often socially and interpersonally devastating) verbal or physical aggression" for individuals suffering from PTSD (Voorhees et al., 2018). As with Steven's guilt, the inclusion of his angry outburst helps illuminate central concepts for each of the explored mental illnesses, providing viewers with a more all-encompassing understanding of the factors influencing Steven's behaviors.

4.3 Self-Isolation

Steven's emotional stability throughout the season is largely crippled by his aversion toward seeking help. During later episodes of the finale season, he becomes increasingly prone to sporadic absences and atypical behaviors, declining to explain them when prompted by his family and friends. For example, in the episode "Prickly Pair", Steven picks up the hobby of gardening to serve as a buffer for the loneliness he feels after witnessing most of his childhood friends move away from his hometown to pursue independent careers. After accidentally growing a sentient cactus with his gem powers, he ends up projecting all of these negative emotions onto it via indignant rants. Around halfway into the episode, he tells the cactus "I can't tell Pearl how I feel, 'cause she'll blame herself and spiral out of control, and I'll have to pick up the pieces. And I don't want any more high-and-mighty advice from Garnet. I just want to know better for once" (Green et al., 2019, 5:11). This dialogue was characterized as excessive worry under GAD (Munir & Takov, 2022) and feelings of estrangement from others under PTSD (Mann & Marwaha, 2022). The narrative's focus on Steven's thoughts and emotions provides viewers insight into the rationale behind his avoidance of others. His self-justifications follow the trend that "those with GAD use worry to shift their intrapersonal

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experiences toward negativity in an attempt to preclude sharp increases in negative emotion" (Newman et al., 2016). Once again, through the accurate depiction of Steven's mental illness symptoms, the audience can better comprehend his personal struggles without reducing him to a set of negative attributes.

4.4 Stigma

Though most of Steven's family and peers demonstrate healthy concern for his depleting emotional wellness, there still exists a select few instances where he's exposed to negative stigmas. The details surrounding the two observed instances of mental health stigma will be discussed below.

Prejudice: Pink Pearl and Pearl

As mentioned prior, Steven displays a violent, agitated outburst in the episode "Volleyball". In the immediate aftermath of his destructive screaming, both Pink Pearl and Pearl exhibit a fear-induced response. Pink Pearl begins visibly trembling and curls into a fetal position, while Pearl steps in front of her to shield her and eyes Steven warily (Guignard et al., 2019). Their combined display of alarm was characterized as an instance of prejudice, as it fell under the category of fear (Fox et al., 2018). Pink Pearl may have exhibited a negative response because Steven's anger was reminiscent of his mother's past tantrums. Pearl, on the other hand, may have backed up to guard Pink Pearl out of concern for her emotional wellbeing, rather than out of fear of Steven himself. Regardless of the reason for their response, their reactions reflect the notion that "prejudice towards people with [mental illness] appears to be an outcome of ideology, personality, and past experiences" (Kenny et al., 2018). The existence of stigma through Pink Pearl and Pearl's prejudice towards Steven still demonstrates that the show isn't impervious to harmful social stereotypes surrounding mentally ill individuals.

Stereotyping: Jasper

In the episode "Fragments", Steven decides to isolate himself in the nearby forest to seek guidance from Jasper, a former enemy of his from prior seasons. He reaches out to her for advice on how to control his gem powers, which had become increasingly unstable due to his worsening emotional state. During the episode, Jasper frequently belittles him and insinuates that he's pathetic for letting his emotions get the better of him (Abrams et al., 2020). To remedy his perceived weakness, Steven takes on Jasper's offer to train his developing powers in the middle of the woods. In an ensuing spar days later, Steven, after being egged on by Jasper, shatters her gemstone in a violent daze, thus destroying her physical form (Abrams et al., 2020).

Jasper's consistent disparaging attitude throughout the episode was classified as stereotyping, as many of the remarks she spouted to Steven before being shattered reinforced the notion that mentally ill people are weak in character (Fox et al., 2018). However, since Jasper is a former antagonist, the viewer is less likely to buy into the ideas she preaches, as much of her personality revolves around the principle that violence and brute force are the best and only means to accomplish one's goals. Even so, Jasper's behavior towards Steven was still largely negative, supporting the prominent stereotype that mentally ill individuals are unreliable in nature (Rössler, 2016). As with the instance of prejudice perpetuated by Pearl and Pink Pearl, the mental illness stigma exhibited through Jasper's harsh stereotyping of Steven demonstrates that Steven Universe Future still has instances that relay negative characterizations of mental illness, though they are very scarce across the selected episodes.

5. Conclusion

One major factor that limited this study was the presence of researcher bias when classifying Steven's behaviors. Given that the study was conducted with the expectation that most of the episodes would portray highly accurate depictions of each mental illness, it's very likely that some of Steven's neutral actions were mistakenly characterized as symptoms of the chosen disorders. Another constraint of the study was the absence of time-related criteria when evaluating each episode's illness diagnoses. Even though this aspect was purposefully removed to allow for greater ease of conducting the symptom analyses, it may have also inflated the accuracy results since a less holistic approach

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was taken towards characterizing Steven's behaviors. Finally, since the study only focused on the finale season of *Steven Universe*, it can't account for the portrayals of mental illnesses in any of the prior seasons, or of the series as a whole.

Regardless of these limitations, *Steven Universe Future* still sets a precedent for a more de-stigmatized outlook toward mental health, especially in children's TV. Its portrayal of mental illness is generally quite accurate and it perpetuates very few stigmas surrounding the treatment of mentally ill individuals. Also, considering how recently the show ended, it provides a promising outlook for future cartoon series seeking to breach the same topics. What remains unclear, though, is whether *Steven Universe* is following a trend of improved mental illness representation or is simply a show that diverges from an existing negative standard.

Steven Universe's ability to breach a subject as complex as mental health to a child audience suggests that children's media plays a key role in combating deep-rooted social stigmas surrounding mental health treatment. Even though the relative effectiveness of early childhood mental illness education is beyond the boundaries of my research, it is a worthwhile subject to explore in future studies.

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Evaluating the Physiological Effect of Supplemental UV light on Malabar Spinach Grown Indoors

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Abstract

The amount of usable farmland is decreasing worldwide as a result of an increasing global population as well as pollution. This means that we must search for ways to increase the efficiency of our agricultural systems. Industrial indoor farming has significantly augmented efforts to grow unique variants of crops and crops in places where the outdoor conditions do not permit natural field growth by growing crops with LED and fluorescent lights; however, this overlooks the possibility of applying UV light to indoor farming. The UV spectrum includes UVA (λ = 315-400 nm), UVB (λ = 280-315 nm), and UVC light (λ = 100-280 nm). While the ozone layer blocks UVC light, UVA and UVB have been shown to have significant impacts on the development and morphology of various plant species. Red Malabar spinach (*Basella alba*) is an important crop in combating food insecurity due to its high nutritional value, high growth rate, and many harvestable parts. This research analyzed the effect of growing Malabar spinach under different UV radiation treatments in an indoor farming setting. Plants were grown for two trials in three chambers: white light (control), white light + UVA, and white light + UVA + UVB (sunlight conditions). For the second trial, the distance between the UV lights and plants was halved. Using an ANOVA and post-hoc Tukey test, statistically significant differences in plant height, leaf surface area, and leaf number were demonstrated between radiation treatments. The results of this experiment demonstrated that the UV treatments outperform the standard LEDs for the aforementioned characteristics with the UVA group showing the most growth. This study highlighted the stimulatory effect of UVA light on Malabar spinach growth and demonstrated the potential for incorporating UVA light into indoor agriculture systems to increase crop yields.

Keywords: Ultraviolet, Malabar Spinach, Indoor Agriculture

1. Introduction

Indoor agriculture has greatly advanced in the last 20 years in response to the decrease in usable farm land worldwide (Avgoustaki and Xyidis, 2020). The main advancements in indoor agriculture Have been centered in the central growth media such as water for hydroponics. In tandem, lighting technology has changed to improve the efficiency of LEDs, which are the most common in indoor agriculture, as well as to optimize the proper amount of light based on the targeted growth result. For these reasons, indoor growers continue to primarily use LEDs to supply light to crops. As a result, one area that has been largely overlooked is the application of ultraviolet (UV) light in indoor agriculture.

The UV spectrum is composed of UVA (λ = 315-400 nm), UVB (λ = 280-315 nm), and UVC light (λ = 100-280 nm) light. UVC light, which is harmful to all living things, is absorbed by Earth's ozone layer and prevented from entering the atmosphere. On the other hand, UVA and UVB permeate the ozone layer and demonstrate significant morphological effects on Earth's plants (Neugart and Schreiner, 2018; Robson et al., 2014; Roeber et al., 2020). Most

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indoor grow lights, especially LEDs, either do not produce significant levels of UV light or have special UV filters for the UVA and UVB light they emit.

This experiment compares the effects of UVA and UVB light on notable crop characteristics such as plant height, leaf number, and leaf surface area of *Basella alba* (red Malabar spinach) grown indoors. Previous research indicates that increased UVB exposure can have inhibitory effects on the aforementioned characteristics whereas UVA can have stimulatory effects (Deckmyn et al., 1994; Jordan, 2002; Kataria et al., 2014; Nogués, 1998; Verdaguer, 2017; Wargent et al., 2009; Zu, 2010). Many of the studies that identify the specific pathways that are affected by UVA and UVB exposure were conducted on non-crop producing plants like *Dunaliella bardawil*, a type of algae (White, 2002). Additionally, there is little research on the impact of the specific effects of UVA and UVB light on leaf-bearing plants such as *Basella alba* (Malabar Spinach). As such, this study explores two novelties: applying UV light to indoor farming and the impacts of UVA and UVB light on Malabar spinach. By supplementing UV light in indoor growth chambers, this research hypothesizes that Malabar spinach exposed to UV radiation will demonstrate increased plant height, leaf surface area, and leaf number compared Malabar spinach exposed to only white light based on similar phenotypes observed in other plant systems.

2. Materials and Methods

2.1 Experimental Setup

This experiment used a growth chamber that was hand-built for this research in a garage. The construction began with the creation of a metal frame made using power conduits. Rods were run from end to end of the growth chamber and the lights were hung from these rods. This allowed for the lights to be adjusted horizontally and vertically as the plants grew to maintain the desired distance of the lights from the plants. Opaque black tarps were used to isolate each of the three chambers: white light (referred to as "control group"), white light + UVA (referred to as "UVA group"), and white light + UVA + UVB (referred to as "UVA + UVB group"). The tarps covered the entire growth chamber to create a separate internal environment.

A white light + UVB group was not tested as previous research has demonstrated that excessive UVB exposure to any plant can cause significant DNA damage (Frohenmeyer and Staiger, 2003; Jordan, 2002; Sharma, 2017; Strid, 1994; Suchar and Robberecht, 2015) and as such UVB was only used in tandem with UVA to mimic natural lighting conditions of outdoor farming. Additionally, Earth's atmosphere cannot prevent UVA light from passing through without some UVB as well. This makes white light + UVB an unrealistic group to test.

The control group had 10 pots while the UVA group and the UVA + UVB group both had 5 pots each (Figure 1). The fewer number of pots in the experimental groups was due to the power limitations of the UVA and UVB lights used which reduced the area that could be exposed while still maintaining significant light intensity at the desired distance.

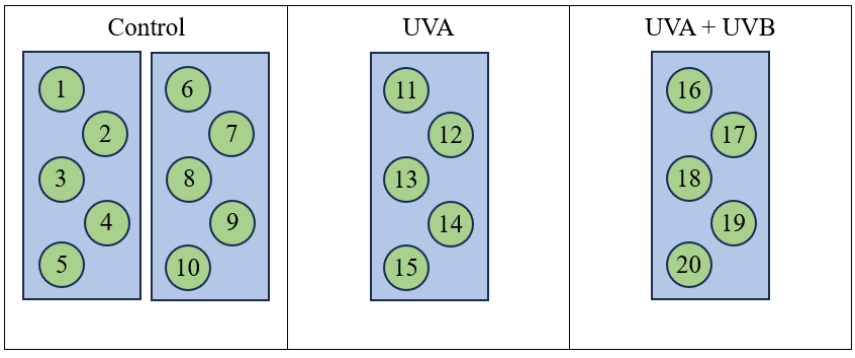

Figure 1: Experimental setup of the pots numbered by group: control group (pots 1-10), UVA group (pots 11-15), UVA + UVB group (pots 16-20).

Malabar spinach was used in this experiment because it is a heat tolerant, fast-growing plant with numerous harvestable parts and high potential as a super food. Typically, Malabar spinach is grown in humid regions in Asia near the equator. Malabar spinach is a fast-growing plant that can thrive in heat which made it an ideal choice for the temperature of the growth chamber which could reach ~29°C in the summer heat. Additionally, it is a highly nutritious plant which could greatly aid in the food crisis if its production could be augmented.

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2.2 Data Collection

To begin trial 1 of this experiment, Malabar spinach seeds were germinated indoors for eight days (this duration was determined from a pilot experiment for optimal germination success) at room temperature (~21°C). The seeds were then planted in 14 cm in Miracle Grow Moisture Control Soil to allow enough room for sufficient root development. Additionally, to increase sample sizes, each pot had 3 seeds planted in it, and the seeds were arranged in a triangle spaced 5 cm from the center of the pot (Figure 2).

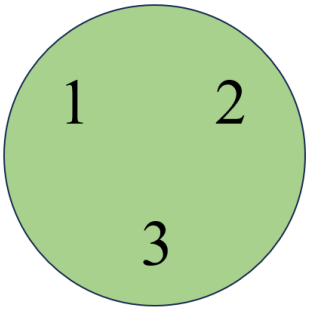

Figure 2: Arrangement of Malabar spinach seeds in each pot.

The seeds were given 12 mL of water daily and only exposed to white light that was 46 cm from the plant (1000 lumens per light strip x 2 strips per chamber with the optimal distance determined by the manufactures of the light) until the cotyledons (the embryonic leaves of the plant which help it begin growing) were grown. The exposure times were long day conditions consisting of 16 hours of light followed by 8 hours of darkness This was based on the optimal growing times for plants only receiving artificial light. After the cotyledons grew fully and the first set of true leaves began to emerge, the UV lights were turned on and followed the same 16 hours of light and 8 hours of no light. For the UV exposure in trial 1, UVA light was 25 cm away (~370 Lux) and UVB light was 15 cm away (~670 Lux). All lights were placed at the optimal distances described by the manufactures (Figure 3).

In trial 2, the plants were replanted in new soil of the same type and the germination, planting, watering, and data collection were the same as trial 1. However, the lights were moved closer to the plants: UVA was 13 cm away (~960 Lux), UVB was 8 cm away (~1410 Lux). The lights were placed slightly closer than the optimal distances determined by the manufactures. All white lights were still 46 cm away (1000 lumens per strip) (Figure 4). The lights were moved closer to determine if supplemental UV light at levels higher than the recommended amount could still increase overall plant growth as compared to plants not exposed to UV light. As such, the trial two plants were exposed to their respective UV lights at distances past their optimal levels. This was not for the purpose of creating two trials of data to be compared against each other, but rather to increase the number of samples to preform statistical analysis on.

Figure 3: Image of trial 1 light setup where UVA light is 25 cm and UVB light is 15 cm away.

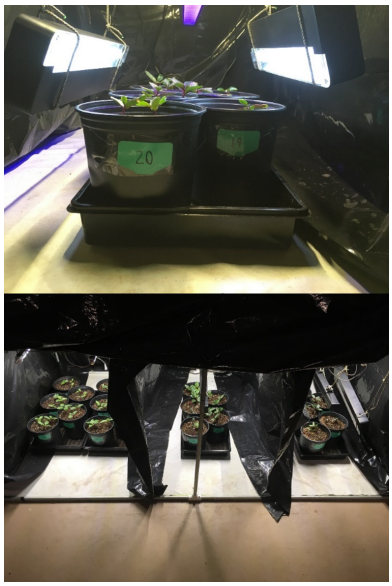

Figure 4: Image of trial 2 light setup where UVA light is 13 cm and UVB light is 8 cm away.

Measurements of plant height (cm), leaf number, and any abnormal features were documented every 6 days in both trials. This allowed for significant growth to occur in between data collection. During data collections, the height of the lights was adjusted accordingly to maintain the treatments predetermined distances. After the 5th data collection (30 days) in both trials, the largest leaf of the plant was removed and placed against a white background with a ruler for reference and overhead light to reduce shadows and a picture of the front and back of the leaf was taken to determine its surface area (cm^2).

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2.3 Data Analysis & Evaluation

Throughout trial 2, because the growth chamber was in a garage, the temperature inside the chamber was subjected to variance from the outside temperature. This did not affect trial 1 significantly because the average temperature outside was ~29°C which resulted in the temperature of the growth chamber being ~23°C. During the second trial, the average outside temperature was ~15°C. An insulating material was added to the outside of the growth chamber which helped to maintain an internal temperature of ~20°C. The temperature was measured with a thermometer during data collection to ensure there was enough insulation to maintain an acceptable temperature. The average internal temperatures for both trials were within the optimal range for Malabar spinach growth (15-27 °C). To ascertain whether the change in temperature between the two trials impacted the distributions of each measured notable crop characteristic, the trial 1 values were plotted against the trial 2 values in a Quantile-Quantile (Q-Q) plot. These plots were used to measure the degree of similarity of the distributions of two datasets. Next, each Q-Q plot was compared with a linear regression to obtain an R^2 value between [0,1]. Higher R^2 values in this range indicated a better correlation (and in this case, a more similar distribution). If the distributions of the plant height, leaf surface area, and leaf number measurements were similar, the values from both trials could be synthesized for the following statistical analyses. The pictures of the biggest leaves from both trials were analyzed using the ImageJ software which examined the surface area of the leaves by using the number of pixels in a premeasured reference area in the picture. All leaf borders were digitally traced on the leaf pictures to eliminate errors in surface area measurements from shadows in some pictures. The final data from each trial for plant height, leaf surface area, and leaf number was analyzed in RStudio. This was done to report findings on the most significant effects that can be seen on the plants, which would be in the final measurements of each trial. These characteristics were analyzed first using an ANOVA summary followed by a TUKEY test. This yielded 3 *p*-values, one for each lighting group's comparison against the other. Each p-value was compared to a significance threshold of 0.05 for all statistical tests, meaning if the p value is greater than 0.05, then measured characteristic was not deemed to be significantly different.

3. Results

3.1 Data Synthesis Validation

The measurements of each notable crop characteristic from both trials were plotted in Q-Q plots and compared with a linear regression to obtain an R^2 value between [0,1]. R^2 values closer to 1 indicate that the data from both trials have similar distributions. The R^2 values for each characteristic are summarized in Table 1. As such the temperature was also not considered a restriction in combining the data between trials 1and 2.

Table 1: R^2 values of the comparisons of the distributions between trials 1 and 2 for each crop characteristic.

Crop Characteristic	R^2 value
Plant Height (cm)	0.951
Leaf Surface Area (cm^2)	0.896
Leaf Number	0.944

The R^2 values observed were 0.951 for plant height, 0.896 for leaf surface area, and 0.944 for leaf number. These values demonstrate that the distributions between the trials 1 and 2 data are highly similar and can be synthesized for the subsequent statistical analyses.

3.2 Notable Crop Characteristic Analysis

After synthesizing the data from both treatment groups, an analysis of variance (ANOVA) test was conducted. The following *p*-values were a result of the ANOVA test which examines all three treatment groups to test if any of them are significantly different – a significance code of 0.05 was used for the ANOVA test as well as all other statistical tests.

Table 2: P values of the ANOVA test for each crop characteristic.

Crop Characteristic	*p*-value
Plant Height (cm)	0.0309
Leaf Surface Area (cm^2)	2.5e-7
Leaf Number	2.11e-6

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This experiment compiled all data in RStudio using Tukey HSD tests to determine significant differences between treatment groups. All measurements from both trials were analyzed to track the overall growth of the plants. When synthesizing data for analysis, the last measurements from each trial were taken.

Each notable crop characteristic was graphed using boxplots with a compact letter display to represent the results of the Tukey HSD test. Graphically, each boxplot has a letter assigned to it based on its statistical significance determined by the Tukey HSD test. The Tukey HSD test compared each treatment against each other to determine significant differences. The compact letter display uses this test and assigns a unique letter to each group that is statistically different from the others. If two groups share a letter, they are not statistically different. If a group has multiple letters, it is not statistically different from any other groups that share a letter with it.

Table 3: TUKEY Test results which show each crop characteristic's p value for the comparison of each treatment group against one another with significant p values being bolded.

Measured Characteristic	Treatments Compared	*P Value*
Plant Height	**UVA - Control**	**0.023**
	(UVB + UVA) - Control	0.812
	(UVB + UVA) - UVA	0.194
Leaf Surface Area	**UVA - Control**	**1.00 e-7**
	(UVB + UVA) - Control	0.084
	(UVB + UVA) - UVA	**5.06 e-3**
Leaf Number	**UVA - Control**	**2.07 e -5**
	(UVB + UVA) - Control	**2.06 e-4**
	(UVB + UVA) - UVA	0.907

The plant height measurements from both trials were graphed by lighting treatment using boxplots and the results of the Tukey HSD test are shown (Figure 5). The average plant heights observed for the UVA group, UVA + UVB group, and control group were 4.72 cm, 3.91 cm, and 3.81 cm, respectively. The UVA group generated the largest plant height on average. Based on the compact letter display, the UVA + UVB group is not statistically different from either the UVA group ($p = 0.194$) or control group ($p = 0.812$). However, the UVA group is statistically different from the control group ($p = 0.023$).

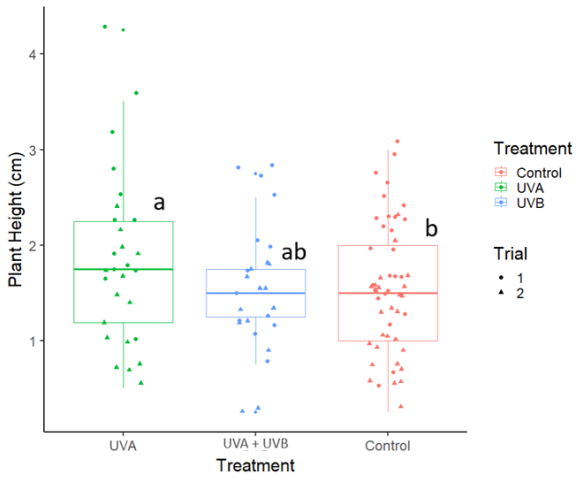

Figure 5. Plant height (cm) by treatment group graph with compact letter display to show significance results of Tukey HSD test.

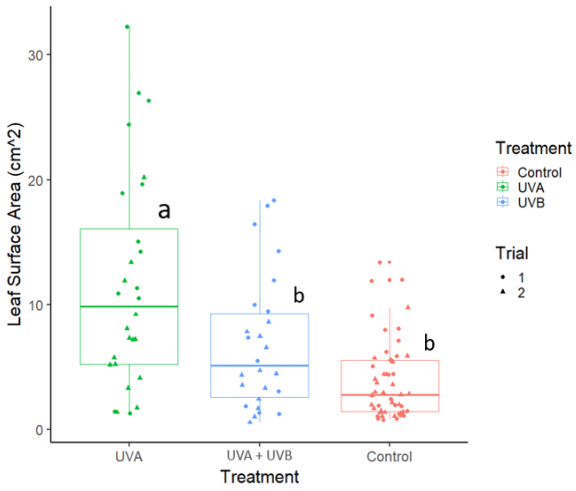

Figure 6. Leaf Surface Area (cm^2) by Treatment Group graph with compact letter display to show significance results of Tukey HSD test.

Similarly, the leaf surface area data were graphed with boxplots based on the lighting conditions and show the compact letter display (Figure 6). The average leaf surface areas observed for the UVA group, UVA + UVB group, and control group were 11.58 cm^2, 7.04 cm^2, and 3.86 cm^2, respectively. The UVA group induced the largest average surface area growth. Based on the compact letter display, the UVA + UVB group and control group are not statistically

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different from each other (p = 0.085). Although these two groups were not statistically different, the UVA + UVB yielded a higher average surface area. On the other hand, the UVA group is statistically different from both the UVA + UVB group (p = 5.06e-3) and the control group (p = 1e-7).

The leaf number values were also graphed by lighting conditions using boxplots with the results from the Tukey test shown (Figure 7). The average leaf numbers observed for the UVA group, UVA + UVB group, and control group were 5.10, 4.96, and 3.67, respectively. While the UVA group had the largest average leaf number, both UV groups notably outperformed the control group. Based on the compact letter display, the UVA group and UVA + UVB group are not statistically different from each other (p = 0.906), but both are statistically different from the control group (p = 2.11e-6 and p = 2.07e-5, respectively).

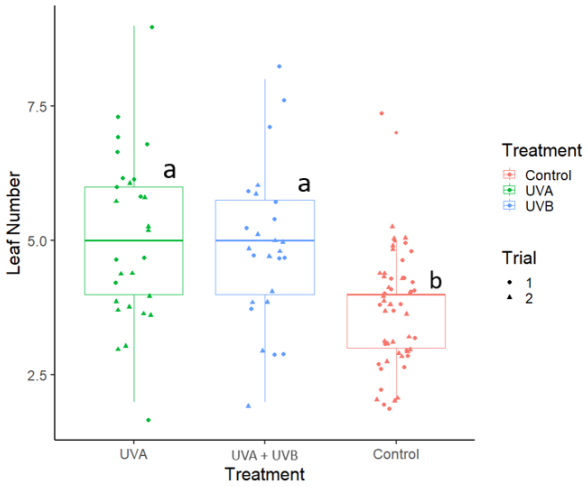

Figure 7. Leaf Number by Treatment Group graph with compact letter display to show significance results of Tukey HSD test.

4. Discussion

This research investigated the hypothesis that Malabar spinach exposed to supplemental UV radiation will have a greater plant height, leaf surface area, and leaf number than Malabar spinach exposed to only white light in indoor growth chambers. The degree of similarity between trial 1 and 2 as found using the Q-Q analysis reveals that the temperature was not a confounding variable for the Malabar spinach, furthermore that trials 1 and 2 were not significantly different which also means that exposure to UV light can still have significant effects on Malabar Spinach growth within the plant's viable temperature range.

For plant height, the UVA group outperformed the other lighting conditions on average but was only statistically different from the control group (p = 0.023). While the UVA group and UVA + UVB group were not statistically different (p = 0.194), the lower average plant height of the UVA + UVB group compared to the UVA group was likely associated with the previously discussed inhibitory effects of UVB light.

For leaf surface area, the UVA group had a higher average than both the UVA + UVB group and control group and was statistically different from both (p = 5.06e-3 and p = 1e-7, respectively). Additionally, the UVA + UVB group had a higher average value than the control group, but these groups were not statistically different (p = 0.085). These measurements show the improved growth of Malabar spinach leaves in indoor farming when exposed to supplemental UV light as opposed to just traditional LEDs. Again, the average of the UVA + UVB group being lower than the UVA group is likely linked to the previously mentioned inhibitory effects of UVB light and stimulatory effects of UVA light.

For leaf number, the UVA group and UVA + UVB group had higher averages than the control group. While the UV groups were not statistically different from each other (p = 0.906), they were both statistically different from the control group (p = 2.11e-6 and p = 2.07e-5, respectively). The leaf number data demonstrate the increased growth of Malabar spinach indoors when exposed to supplemental UV light compared to just LED light.

The results from this study demonstrate that growing Malabar spinach indoors with supplemental UV light yields increased plant height, leaf surface area, and leaf number compared to traditional LED lights. Specifically, the stimulatory effects of UVA light demonstrate an increase in all aforementioned crop characteristics. Albeit the UVA + UVB group performed lower on average than the UVA group in plant height and leaf surface area (with a statistical difference observed in the latter), no conclusions about the effects of UVB light specifically can be made since no white light + UVB group was tested.

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4.1 Limitations

One limitation during this experiment was the intensity of the light sources used. The UVA and UVB lights used were near the lower ends of their respective UV ranges, so lights with wavelengths further into the range could yield more statistically significant results or, as seen in some plants, promote certain growth factors. Solutions to this are to use lights that are of higher intensity or to create an experimental setup that can incorporate more lights. Additionally, a problem that arose when conducting trials 1 and 2 was that the outside temperature began to decrease which resultingly lowered the temperature inside of the plant chambers. While this did not hinder the significance tests in this experiment, one way to overcome this is to run the experiment in an indoor environment that has temperature control or to conduct the study during the same season to ensure a constant average temperature.

4.2 Future Work

This research can be continued to identify the most efficient use of UVA light in indoor growth structures. Specifically, by testing different wavelength ranges of UVA light and measuring pigment concentrations to understand its effects on photosynthetic efficiency (Basahi et al., 2014; Grammatikopulos et al., 1994). Additionally, to maximize the potential applications of UVA light, it is necessary to further experiment on the optimal exposure times as well as UVA wavelength. Another avenue for future research is to measure terpene and flavonoid concentrations, both of which are a general label for plant molecules that influence our perception of taste and smell of a plant. The application of UV light can be used to affect terpene and flavonoid concentrations to adjust taste and scent for different market applications. Moreover, certain terpenes and flavonoids can be isolated for medicinal use such as cancer-combative medications (Ni et al., 2020; Ullah, 2020).

5. Conclusion

This experiment supports the hypothesis that exposing Malabar spinach to UV light indoors will increase plant height, leaf surface area, and leaf number compared to traditional LED light used in indoor farming. Specifically, this research demonstrates the stimulatory effects of UVA and not UVB light on Malabar spinach for the aforementioned characteristics in an indoor setting. Furthermore, it helps demonstrate the potential of using supplementary UV light in indoor agriculture to promote growth in crop relevant characteristics for Malabar spinach as well as other crops. Hopefully, this research can be used to improve indoor agricultural efficiency and help pave a path toward combating the global food crisis.

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On the Application of Inequalities Containing Sums of Minimum/Maximum of Numbers

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Abstract

Retail inventory management is a crucial part of many businesses due to the high profit associated with it as well as the uncertainty around it, especially for industries with short production cycles and a complex supply chain. Proper management of retail inventories can lead to decreased inventory costs, prevent spoilage and obsolescence, and improve customer satisfaction, all of which lead to increased profits for the company. In this paper, we first stated a well-known inequality. The inequality involves multiple variables and how the maximum/minimum values of a subset of the numbers compare to the maximum/minimum values of the whole set of numbers. After demonstrating this inequality is true, we further proved generalizations of the inequality. With these, we applied our results to the retail inventory management problem. A model for such problem was taken from Ozbay, 2006. Finally, we provided an upper and lower bound for the cost of inventory management. These results might allow companies to make better long term decisions due to the bounds being rigorously proven. However, more work can be done to further improve the bounds in special cases as well as combining the results with other algorithms.

Keywords: Algebraic optimization, Inequalities, Retail inventory management

1. Introduction

Backlogging and inventory holding costs are two major costs of inventory management (Misra, 2022). Such costs arises when there is either extra or shortage of goods. Some notable examples such as the 2017 backlog when Apple launched its iPhone X (Williams, 2017), which caused many to criticise Apple's poor forecasting. Therefore, companies need to calculate the amount of goods that needs to be stored or imported to make sure they always have sufficient goods to meet customer demands.

Inequalities refers to a topic in algebra which investigates the relationship between certain numbers, usually on their size. It often makes use of some common inequalities like AM-GM, Cauchy's inequality (Mitrinovic et al., 2013), or may use other methods like smoothing or even calculus to prove an inequality. Such inequalities are traditionally used in many Mathematics Olympiad questions, with many books covering such area (Sedrakyan et al., 2018; Manfrino et al., 2009; Su et al., 2015). Inequalities that appear in Mathematics contests often comes in the form of proving a certain known identity, and contestants are required to provide a proof showing the above inequality is correct. However, in the past few years, inequalities have seen a wider range of applications from biology (Feng et al., 2016) to managing supplies and inventories in supermarket sales (Agnew, 1975; Moon et al., 2010; C´ardenas-Barr´on et al., 2011).

Retail inventories management is the process of ensuring the company have enough inventory to meet customer demand while that also not having an excess or shortage of goods (Luther, 2021). One classical approach to this problem uses the Economic Order Quantity (EOQ), which is a formula to determine the optimal quantity to order,

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with the amount of ordering given by $\sqrt{2A * O * C}$ (Kumar, 2016; Agarwal, 2014). Another method for inventory management, known as the (s, S) policy, is also widely adopted (Ma et al., 2019). Such problems are sometimes maintained by automated inventory management systems (Samuel, 2012), or may include more complicated methods such as Bayesian methods (DeHoratius et al., 2008) to account for inaccuracies in inventory records.

The goal of this research is to provide explicit algebraic expressions that can bound or estimate the total cost needed for retail inventory management. With these results, companies would be able to estimate the cost for retail inventory management. This would allow them to make better planning, and avoid making the same mistake as Apple. However, due to the complicated nature of such problems, the bounds may not be especially strong and more detailed analysis might be needed to obtain stronger results with more real life applications.

The remainder of this paper is divided as follows. Section 2.1 and 2.2 will first present an inequality and its generalizations. The inequality involves the minimum/maximum of some numbers and the relationship between them. This was then applied to retail inventory management in section 2.3, which used it to strictly bound the cost of inventory storing to determine whether the company has reached the shutdown point in classical economics. The paper finished off with results and limitations (sections 3 and 4) and comparative analysis (section 5).

2. Materials and Methods

2.1 Original Inequality (known)

Most of the following results builds upon an known inequality. The following section provides a prove of that inequality. Before going directly into the proofs, here are some of the notations that are used throughout this paper.

- $min\{a_1, a_2, \cdots, a_n\}$: The minimum of numbers $a_1, a_2, \cdots, a_n$
- $max\{a_1, a_2, \cdots, a_n\}$: The maximum of numbers $a_1, a_2, \cdots, a_n$
- $\forall$: For any
- WLOG: Without Loss of Generality

Besides those notations, the concept of smoothing would also be used later in this paper. Smoothing, at least in the context of inequalities, refers to the idea of making minor adjustments to certain variables. Consider a function which has a minimum when all numbers are equal. To prove that with smoothing, one method is to show that the function is smaller when two unequal values are replaced with two equal ones. This result can then be repeatedly applied to show that the function achieves the minimum when all values are equal. A more detailed explanation can be found online at DanielWainfleet (2019).

Now, moving on to the proofs. First, a short lemma.

Lemma 2.1: $min\{a, b\} \leq ta + (1-t)b, \ \forall\, 0 \leq t \leq 1$

Proof. Without loss of generality (WLOG), let $a \leq b$

Then, the above is equivalent to $(1-t)a \leq (1-t)b$, which immediately follows from $a \leq b$ and $1 - t \geq 0$

Next, the following theorem holds:

Theorem 2.2: *Let* $a_1, a_2, \cdots, a_n$ *be real numbers such that* $a_1 + a_2 + \cdots + a_n = 0$.

Then, the following is true

$$\frac{n}{n-1} min\{a_1, a_2, \cdots, a_n\} \geq min\{a_1, a_2\} + min\{a_2, a_3\} + \cdots + min\{a_{n-1}, a_n\} + min\{a_n, a_1\}$$

Proof. WLOG, $a_n = \min\{a_1, a_2, \cdots, a_n\}$

It is then sufficient to show that $-\frac{n-2}{n-1} a_n \geq \min\{a_1, a_2\} + \min\{a_2, a_3\} + \cdots \min\{a_{n-2}, a_{n-1}\}$

Notice that $-a_n = \sum_{i=1}^{n-1} a_i$, Hence, by repeatedly applying lemma 2.1,

$\min\{a_1, a_2\} + \min\{a_2, a_3\} + \cdots \min\{a_{n-2}, a_{n-1}\} \leq$

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$$\left(\frac{n-2}{n-1}a_1+\frac{1}{n-1}a_2\right)+\left(\frac{n-3}{n-1}a_2+\frac{2}{n-1}a_3\right)+\cdots\left(\frac{1}{n-1}a_{n-2}+\frac{n-2}{n-1}a_{n-1}\right)=\frac{n-2}{n-1}\sum_{i=1}^{n-1}a_i=-\frac{n-2}{n-1}a_n$$

As desired.

2.2 Generalization of the Inequality

In this section, some generalizations of the above inequality will be presented. First, a corollary.

Corollary 2.3: *Let $a_1, a_2, \cdots, a_n$ be real numbers such that $a_1 + a_2 + \cdots + a_n = 0$.*
Then the following relations holds:

$$\frac{n}{n-1}max\{a_1,a_2,\cdots,a_n\}\le max\{a_1,a_2\}+max\{a_2,a_3\}+\cdots+max\{a_{n-1},a_n\}+max\{a_n,a_1\}$$

Proof. Set $a_i' = -a_i$ and applying Theorem 2.2. Since $\min\{a,b\} = -\max\{-a,-b\}$, $\min\{a_1,a_2,\cdots,a_n\} = -\max\{-a_1,-a_2,\cdots,-a_n\}$ etc, the corollary immediately follows.

The above results can be further generalized.

Theorem 2.4: *Let $a_1, a_2, \cdots, a_n$ be real numbers such that $a_1 + a_2 + \cdots + a_n = 0$. Then*

$$\frac{n}{n-1}min\{a_1,a_2,\cdots,a_n\}\ge min\{a_1,a_2,a_3\}+min\{a_2,a_3,a_4\}+\cdots+min\{a_{n-1},a_n,a_1\}+min\{a_n,a_1,a_2\}$$

$$\frac{n}{n-1}min\{a_1,a_2,\cdots,a_n\}\ge min\{a_1,a_2,a_3,a_4\}+min\{a_2,a_3,a_4,a_5\}+\cdots+min\{a_{n-1},a_n,a_1,a_2\}+min\{a_n,a_1,a_2,a_3\}$$

$$\frac{n}{n-1}min\{a_1,a_2,\cdots,a_n\}\ge min\{a_1,a_2,\cdots,a_{n-1}\}+min\{a_2,a_3,\cdots,a_n\}+\cdots+min\{a_n,a_1,\cdots,a_{n-2}\}$$

Proof. Notice the following inequality: $\min\{a_1,a_2,a_3\}\le\frac{1}{2}\min\{a_1,a_2\}+\frac{1}{2}\min\{a_2,a_3\}$

Hence, $min\{a_1,a_2,a_3\}+min\{a_2,a_3,a_4\}+\cdots+min\{a_{n-1},a_n,a_1\}+min\{a_n,a_1,a_2\}\le$

$$\left(\frac{1}{2}\min\{a_1,a_2\}+\frac{1}{2}\min\{a_2,a_3\}\right)+\left(\frac{1}{2}\min\{a_2,a_3\}+\frac{1}{2}\min\{a_3,a_4\}\right)+\cdots$$

$$+\left(\frac{1}{2}\min\{a_{n-1},a_n\}+\frac{1}{2}\min\{a_n,a_1\}\right)+\left(\frac{1}{2}\min\{a_n,a_1\}+\frac{1}{2}\min\{a_1,a_2\}\right)\le$$

$$min\{a_1,a_2\}+min\{a_2,a_3\}+\cdots+min\{a_{n-1},a_n\}+min\{a_n,a_1\}\le\frac{n}{n-1}min\{a_1,a_2,\cdots,a_n\}$$

Similarly, note that:

$$\min\{a_1,a_2,\cdots,a_k\}\le\frac{1}{2}\min\{a_1,a_2,\cdots,a_{k-1}\}+\frac{1}{2}\min\{a_2,a_3,\cdots,a_k\}$$

Hence, following a similar logic as above,

$$\min\{a_1,a_2,\cdots,a_k\}+\min\{a_2,a_3,\cdots,a_{k+1}\}+\cdots+\min\{a_n,a_1,\cdots,a_{k-1}\}\le$$
$$\min\{a_1,a_2,\cdots,a_{k-1}\}+\min\{a_2,a_3,\cdots,a_k\}+\cdots+\min\{a_n,a_1,\cdots,a_{k-2}\}$$

Which finishes by the induction hypothesis for groups of $k-1$ numbers.

2.3 Application of the Inequalities

In this section, some applications of the above-mentioned inequalities are presented. The inequalities were applied as Robust Inventory Problems. This area focuses on the study of inventory management by a company in order to maximize profits or other objectives.

This paper used the model described in (Ozbay, 2006), chapter 1.2 to model the supply chain and the demands for a specific company. In the model by Ozbay, 2006, the inventory management problem is considered over a discrete

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time period of $t = 1,2,\cdots,T$. x_i denotes the amount of inventory at the start of time i, which can be negative to indicate a shortage. Per unit inventory holding cost is denoted by h_i, which is non-negative by definition. Backlogging cost is represented by b_i, and is non-positive since shortage is denoted by a value less than 0. A production cost c_i is also defined in the paper (by Ozbay). In all of the above notations, a subscript i indicates the value at time i.

The original paper then described three processes that happen at time i:

1. An order of quantity $u_i \geq 0$ is made, increasing the inventory to $x_i + u_i$ and incurring a cost of $c_i u_i$
2. A demand $d_i \geq 0$ is served, decreasing the inventory to $x_{i+1} = x_i + u_i - d_i$
3. At the end of period i, a cost of $\max\{h_i x_{i+1}, b_i x_{i+1}\}$ is paid

To better illustrate why the final cost paid is given by the maximum of the two numbers, the following cases can be considered:

1. The company has a positive inventory (i.e., $x_i \geq 0$). In this case, from $h_i \geq 0$, $b_i \leq 0$, it follows that $h_i x_i \geq 0 \geq b_i x_i$. Hence, $\max\{h_i x_i, b_i x_i\} = h_i x_i$, which is desired since a positive inventory would mean paying an inventory holding cost.
2. Conversely, if the company has a negative inventory (i.e., $x_i < 0$), then $h_i x_i \leq 0 \leq b_i x_i$ (again due to the signs of h_i and b_i). Hence, $\max\{h_i x_i, b_i x_i\} = b_i x_i$, which is again desired since a negative inventory would necessarily pay a backlogging cost.

Hence, the total cost at the end of period T can be written as:

$$\sum_{i=1}^{T}(c_i u_i + \max\{h_i x_i, b_i x_i\}) = \sum_{i=1}^{T} c_i u_i + \sum_{i=1}^{T} \max\{h_i x_i, b_i x_i\}$$

Notice that the second term in the above equation is in the form of sum of maximum of numbers, which allowed previous theorem to be applied to obtain a bound for the second term and the total cost.

To convert the above into the form of previous inequalities, first substitute $a_{2i-1} = h_i x_i$ and $a_{2i} = b_i x_i$. Notice that $a_{2i-1} a_{2i} = h_i x_i b_i x_i = h_i b_i x_i^2 \leq 0$ as $h_i \geq 0$, $b_i \leq 0$.

Let $S = \sum_{i=1}^{T}(h_i x_i + b_i x_i) = \sum_{i=1}^{2T} a_i$. Further define $a_{2T+1} = -S$. Then, $\sum_{i=1}^{2T+1} a_i = 0$.

There are now two cases depending on the sign of S.

Case 1: $S \geq 0$

Hence, by corollary 2.3 on $2T+1$ numbers,

$\frac{2T+1}{2T}\max\{a_1, a_2, \ldots, a_{2T}, a_{2T+1}\} \leq \max\{a_1, a_2\} + \max\{a_2, a_3\} + \cdots + \max\{a_{2T}, a_{2T+1}\} + \max\{a_{2T+1}, a_1\}$ (

Notice that $\sum_{t=1}^{T}(\max\{h_t x_{t+1}, b_t x_{t+1}\}) = \max\{a_1, a_2\} + \max\{a_2, a_3\} + \ldots + \max\{a_{2n-1}, a_{2n}\}$.

Now, the following theorem holds:

Theorem 2.5: *Let $a_1, a_2, \cdots, a_{2n-1}, a_{2n}$ be real numbers such that $a_{2i-1} a_{2i} \leq 0 \; \forall \; 1 \leq i \leq n$. Then for $n \geq 2$*

$\max\{a_1, a_2\} + \max\{a_3, a_4\} + \cdots + \max\{a_{2n-1}, a_{2n}\} \geq$

$\max\{a_2, a_3\} + \max\{a_4, a_5\} + \cdots + \max\{a_{2n-2}, a_{2n-1}\} + \max\{a_{2n}, a_1\}$

(Notice that the above inequality is not symmetric due to the condition being only $a_{2i-1} a_{2i} \leq 0$, not $a_{2i} a_{2i+1} \leq 0$).

Proof. The technique of smoothing can be used

WLOG, $a_1 \geq a_2$.

When $a_{2i-1} \geq a_{2i}$ for all $1 \leq i \leq n$, $LHS = a_1 + a_3 + a_5 + \ldots + a_{2n-1} = RHS$, so the inequality obviously holds.

Else, exist $a_{2i-1} < a_{2i}$. WLOG, let that be a_3 and a_4.

Now split into two cases:

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Case 1.1.

If $a_5 \geq a_6$, swap the order of a_3 and a_4 (i.e., let a_3'=a_4, a_4'=a_5) Notice that the value of LHS do not change. Hence, all is left to show that the value of RHS does not decrease. Note that $a_1 \geq a_2$, $a_1 a_2 \leq 0$, hence $a_2 \leq 0$. Similarly, from $a_3 < a_4$, $a_3 a_4 \leq 0$, it can be obtained that $a_3 \leq 0$. Hence, $\max\{a_2, a_3\} \leq 0$. Let Δ represent the new RHS value subtracting the old RHS value. Note that $a_3 \leq a_4$, $a_5 \geq a_6$. Hence, $a_4 \geq 0$, $a_5 \geq 0$.

$$\Delta = max\{a_2, a_3'\} + max\{a_4', a_5\} - max\{a_2, a_3\} - max\{a_4, a_5\} =$$
$$a_3' + a_5 - max\{a_2, a_3\} - max\{a_4, a_5\} = a_4 + a_5 - \max\{a_2, a_3\} - max\{a_4, a_5\} \geq$$
$$= a_4 + a_5 - 0 - max\{a_4, a_5\} \geq \min\{a_4, a_5\} \geq 0$$

Where Δ being positive shows an increase in RHS value after the swap of a_3 and a_4.

Case 1.2. Else $a_5 \leq a_6$

If $a_7 \geq a_8$, then swap a_5 and a_6. The proof concludes using an argument similar to the one above.

Otherwise, $a_7 < a_8$.

But note that such process ($a_{2i-1} \leq a_{2i}$) cannot continue forever, and there must exist i such that $a_{2i-1} \geq a_{2i}$. This is due to $a_1 \geq a_2$, which guarantee such i exists as the original equation is cyclic. The proof also concludes by using similar reasoning. Hence, by theorem 3.1 and noting that $a_1 = a_{2T} = 0$, $a_{2T+1} = -S \leq 0$,

$$\sum_{t=1}^{T} (\max\{h_t x_{t+1}, b_t x_{t+1}\}) = \max\{a_1, a_2\} + \max\{a_3, a_4\} + \ldots + \max\{a_{2T-1}, a_{2T}\} \geq$$
$$\frac{1}{2}(\max\{a_1, a_2\} + +\max\{a_2, a_3\} + \ldots + \max\{a_{2T-1}, a_{2T}\} + \max\{a_{2T}, a_1\}) =$$
$$\frac{1}{2}(\max\{a_1, a_2\} + +\max\{a_2, a_3\} + \ldots + \max\{a_{2T-1}, a_{2T}\} + \max\{a_{2T}, a_{2T+1}\} + \max\{a_{2T+1}, a_1\} =$$
$$\geq \frac{2n+1}{2n} \max\{a_1, a_2, \ldots, a_{2n}, a_{2n+1}\}$$

which provides a lower bound on the minimum possible cost experienced during the T days.

Case 2: $S < 0$

Using the result of case 1 and substituting $a_{2i-1} = -h_i x_i$, $a_{2i} = -(-b_i x_i) = b_i x_i$,

$$-S = \max\{a_1, a_2\} + \max\{a_3, a_4\} + \ldots + \max\{a_{2T-1}, a_{2T}\} \geq \frac{2n+1}{2n} \max\{a_1, a_2, \ldots, a_{2n}, a_{2n+1}\}$$

Hence, multiplying both sides by -1 and noting that $\min\{a_1, a_2, \ldots, a_n\} = -max\{-a_1, -a_2, \ldots, -a_n\}$,

$$-S \leq \frac{2T+1}{2T} \min\{h_1 x_1, b_1 x_1, h_2 x_2, b_2 x_2, \ldots, h_T x_T, b_T x_T, a_{2T+1}\}$$

As $a_{2i-1} = -h_i x_i, a_{2i} = -b_i x_i$

This provides an upper bound for the possible cost of inventory management.

2.4 Relation to shutdown point

Now, imagine a company A which sells a product B for a marginal profit of p_i on the ith day for i from 1 to T. Each day the company receives a demand $d_i \geq 0$. It has a per unit inventory holding cost of h_i and a backlogging cost $b_i \leq 0$. If the company is currently earning an economic loss, it should shut down if the price is greater than the average variable cost according to most economic textbooks (Samuelson et al., 2021). Although some authors challenge this believe (Sprout 2016; Wang et al., 2004), its usage does not significantly alter the results. To find the average variable cost, one component of that would be the inventory management costs. The definition of a_i below is the same as above. The company should shut down if the price is below the average variable cost, which means that if the marginal

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profit of the *i*th goods is less than the minimum possible value of inventory management cost (which is given by equation 23), then the company should definitely shutdown. However, if the marginal profit of the *i*th goods is still larger than or equal to the average variable cost, the company can continue to produce. The above shutdown point *i* is given by this equations:

$$p_i \geq \frac{2i+1}{2i} \max\{a_1, a_2, \dots, a_{2i}, a_{2i+1}\}$$

$$p_{i+1} \leq \frac{2i+3}{2i+2} \max\{a_1, a_2, \dots, a_{2i}, a_{2i+1}\}$$

Conversely, if the marginal profit of the *i*th goods is greater than or equal to the maximum possible cost of inventory management, then the company should continue to produce. The following table summarized the results from this section.

Shutdown	$p_i < \frac{2i+1}{2i} \max\{h_1x_1, b_1x_1, h_2x_2, b_2x_2, \dots, h_ix_i, b_ix_i, a_{2i+1}\}$
Continue Producing	$p_i \geq \frac{2i+1}{2i} \min\{h_1x_1, b_1x_1, h_2x_2, b_2x_2, \dots, h_ix_i, b_ix_i, a_{2i+1}\}$

However, the above result may only be partially applicable depending on the sign of S.

3. Results

This paper presented a previously known inequality and then generalized it to other cases using a similar approach. These results were then applied in a retail inventory management problem with a model of retail inventory management from Ozbay, 2006. Smoothing was then used to prove another theorem, which was necessary for the final result.

The result of the lower bound shows that the total cost needed should be no smaller than a fraction larger than the maximum of all values. This is expected since the expression of the total cost is clearly greater than the maximum of all numbers.

The upper bound shows that the total cost cannot exceed a certain value. An explanation for this would be to note that $S \leq 0$, meaning that left-hand side is small.

4. Limitations

There are a few limitations that could be improved in future works. First, this paper assumes a simple model outlined in section 2.3. In real life scenarios, the problem is often much more complicated and involves more than one supplier or consumer. Hence, this limits the application of the results. Second, the inequalities are unfortunately quite weak. Although they provide exact bounds and were rigorously proven, they may not be very useful in real life.

To solve those limitations, the results from this paper could be integrated into other methods or algorithms. For example, the alpha-beta pruning or the branch-and-cut algorithms all rely on bounding and error estimation for efficiency. More specifically, if the optimal answer will never be found in one case, the algorithm can save time by ignoring that case. Hence, with suitable bounding, such cases can be identified more efficiently, allowing for a better run time.

5. Comparative Analysis

The retail inventory management problem falls under the area of optimization. In optimization, many methods require the use of calculus or analysis, such as the Karush–Kuhn–Tucker conditions (Ghost et al., 2019) or Lagrange multipliers (Sabach et al., 2022). Others uses tools such as linear programming to solve the optimization problem (Vanderbei, 2020). However, polynomials above degree four are not solvable (Żołądek, H. 2000). Hence, purely analytic solutions are rarely used (icurays1, 2017).

In this case, retail inventory management problem often uses algorithms such as machine learning (Gurnani et al., 2021; Gijsbrechts et al., 2022) or other algorithms (Yu et al., 2019). As far as the authors know, there is no purely analytic approach due to the complexity of such problems. Hence, it is difficult to have a meaningful comparison between the algorithms.

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Measuring Shock Impact with Different Ice Hockey Helmets

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Abstract

Shock impact injuries in ice hockey are common, and they cause major brain injuries. Protective helmets can reduce such risks. The purpose of this study was to explore the effects of two types of helmets (with and without a cage) on shock impact to the head. The secondary purpose was to compare the effectiveness of the four different helmets from popular brands (Nike, Bauer, and Reebok), and see which one of the four helmets receives the least amount of shock impact. To test the shock impact on different helmets, they were put on a mannequin's head. The shock impact was measured by the Vibrometer App by ExaMobile on an iphone. The phone was placed inside the helmet, by the left ear of the mannequin, on the opposite side of the impact. It was hypothesized and found that the shock impact to head was less when the helmet had a cage as opposed to not. Additionally, out of the two helmets with a cage, the shock impact to head was less when Bauer IMS 5.0 brand helmet was used as compared to the Reebok 3K brand helmet. It was concluded that helmets with cages are critical, and youth ice hockey players should use caged helmets that are manufactured by Reebok and Bauer.

Keywords: Shock impact, Injury, Ice hockey, Helmet

1. Introduction

Shock impact injuries are very common in ice hockey. Shock is a sudden vibration caused by force such as impact, kick, or explosion. The shock impact is how strong the vibrations are after an impact to the body. Vibrations are measured by the amount of acceleration which is the change in velocity or speed per time interval. They can happen in many various ways, such as, body checking, back checking, fighting, getting hit by a puck, and more. Not many people understand that head injuries are very dangerous and can even, rarely, cause death. In this study, prevention methods were examined, specifically types of helmets that reduce shock impact to help ice hockey players decide on their helmet choices.

A concussion is a type of brain injury that can be caused by a direct blow to the head. It is also known as a Mild Traumatic Brain Injury. This type of brain injury has the power to interfere with how the brain works, such as, loss of memory, judgement, reflexes, speech, balance, coordination, and sleep patterns (McCrory, Meeuwisse, Aubry, 2013). The brain is made of a soft tissue and is cushioned by spinal fluid. It is encased in the hard protective skull. When a person gets a head injury, the brain can slosh around inside the skull and even bang against it. This can cause bruising of the brain and torn blood vessels (Rechel et al., 2008). In most cases, consciousness is not common. Concussions are a potential negative outcome, which can cause a great number of movements of the brain or jarring. The most common signs of a concussion are headaches, dizziness, confusion, disorientation, and blurred vision (McCrory et al., 2009). Sports medicine researcher Guskiewicz and his colleagues (2000) found that the rate of loss of consciousness and headaches, in 1019 cases, were 8.9% and 86%.

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Concussions are very common. About 3 million US citizens have concussions per year. Currently, 5.3 million Americans need long term, or lifelong, help with daily life activities, due to this brain injury (Center for Disease Control and Prevention. 2009). The Center for Disease Control and Prevention estimates about 207-830 emergency room visits per year during the years of 2001-2005. During those same years, there were 1.6-3.8 million emergency room visits in the United States. In the years 2007-2013, Emergency room visits for traumatic brain injuries increased by 47%. But hospitalization decreased by 2.5% and death rates decreased by 5%. In 2012, 329,290 children were treated. A researcher named Benson studied and found that team physicians reported, in the US, concussions and TBI (Taylor, Bell, Breiding, Xu, 2017). Also, there were 559 concussions during regular season games with an estimated rate of 1.8 concussions per 1,000 player hours. This is how often a concussion happens.

Many people who have concussions can experience post-concussional symptoms, such as headaches, dizziness, fatigue, impaired focus, and an increased sensitivity to light and sound. Symptoms usually stop within a few weeks, but, in a small proportion of individuals, they can last longer and can be responsible for prolonged changes in cognitive function (Toy et al., 2014). While rare, a second concussion before the brain has had a chance to recover can cause life-threatening brain swelling, and repeated concussions could cause progressive cognitive decline. lso, after a concussion, it is recommended that you avoid your triggers (a trigger is an activity that increases symptoms), get some sleep, rest your brain, and rest your body.

1.1 Why is studying concussion in sports important?

Sports are a huge part of the American lifestyle and has been throughout our history. Repetitive concussion in sports is associated with brain injuries such as second impact syndrome (Tator et al., 2019), metabolic brain vulnerability and chronic traumatic encephalopathy (Musemici et al., 2019). Therefore, studying concussions is very important in reducing such injuries. Different groups, including athletes, parents and advocacy groups raised their concerns regarding the safety of athletes. However, research that studies concussion and its long-term effects is still limited (O'Halloran et al., 2022). Additionally, more research is needed to explore prevention strategies. Eliason et al.'s (2023) meta-analyses indicated that preventive strategies include using mouthguards, disallowing bodychecking in child and adolescent ice hockey, limiting contact in practices, implementation of neuromuscular training warm-up programs. However, this meta-analysis did not mention types and brands of gears that reduce concussion and TBI. All these studies about brain and head injuries bring awareness to the people playing a certain sport and let them play safe. These tests are not only for professionals, but also for amateurs (Center for Disease Control and Prevention, 2010).

Brain injuries happen in ice hockey in many ways. One way is body checking. Body checking is a useful skill in winning hockey games but is a major risk for injury. Body checking is not illegal in the NHL, but using hands and the stick to hit others is illegal and will cause a penalty. Also delivering a check to a player without the puck is illegal. Researcher Agel et al. (2007) found that the highest amount of game injuries, about 50%, resulted from body checking. It is also 86% of injuries for 9–15-year-olds. Some leagues, not professional ones, do not allow contact. Players in contact leagues are 4 times more likely to be injured, and 12 times more to get fractured than non-contact leagues. Among the 9–15-year-olds, 45% of injuries are caused by legal checks and 8% is caused from illegal checks. Now, hockey pucks are worse. A fan during an NHL game was hit by a hockey puck because it went flying above the boards and hit her. This shows how dangerous a hockey puck can be once hit in the face (Cusimano et al., 2011; Macpherson et al., 2006).

1.2 Injury prevention in ice hockey

Brain injury prevention has always been a topic in ice hockey. In fact, hockey players have an advantage in protecting their head and neck. One advantage is the slickness of the ice. If the body of the player can slide when striking the ground, it deflects the energy that might have otherwise caused the spine to be jarred or jammed if the body could not move upon impact. Also, unlike football, there is no head-to-head contact in ice hockey (Andrews & Yaeger, 2013). Protective gear such as helmets and mouthguards have been recommended over the years. A

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mouthguard is a device that helps protect the teeth and gums. Helmets are best for preventing skull fractures and direct injury to the head. Any player who makes a hard impact with the ice or a player should be examined. They have not shown how to completely prevent concussions, but how to reduce it (Pedersen et al., 2014).

There are many different types of ice hockey helmets. There are ones with cages, half visors, full visors, and simply ones with no cages at all. The most popular brands are Bauer, Reebok, Easton, and CCM. The gear that most professionals wear is Bauer. Each helmet brand is unique in their one way. The Easton E700 weighs 12.2 oz, has a polycarbonate shell, and has a width of 8.31 in. The Reebok 11K weighs 520 grams, has an aerodynamic plastic shell, and has tool free size adjustability. These are just a few of many different types of helmets out there, but this shows that each helmet is different in their own way and is useful in their own way. There have also been studies and tests on ice hockey helmets. In 2011, Virginia Tech University researchers, Cusimano et al., set up an impact test on 38 different types of ice hockey helmets. After they tested each one, they rated each helmet on a scale from 0-5, 5 being the best. They found out that the Bauer Re-Akt 100, which sells for $269.99, received the highest rating of 5.

1.3 The problem statement and hypotheses

Shock impact injuries, especially head injuries, are very dangerous and common in ice hockey. Protecting hockey players' head and neck is very critical to injury prevention. Although hockey players are required to use protective gear such as helmets, the effectiveness of different types of helmets is still being researched (Eliason et al., 2023). There are many different types of ice hockey helmets. The purpose of this study is to explore the effects of two types of helmets (with and without a cage) on shock impact to the head. The secondary purpose is to compare the effectiveness of the four different helmets from popular brands (Nike, Bauer, and Reebok), and see which one of the four helmets receives the least amount of shock impact.

The first hypothesis is that the shock impact to the head is less when the helmet with a cage is used as opposed to when the helmet without a cage is used. The reason is that the cage increases the weight of the helmet, therefore the impact lessens. The second hypothesis is that, out of the two helmets with a cage, the shock impact to head is less when Bauer IMS 5.0 brand helmet is used as compared to the Reebok 3K brand helmet is used. The reasoning is that Bauer IMS 5.0 has a thicker interior padding made of dual density foam. It has a bigger and longer ear protector and a bigger chin protector. Therefore, it should absorb more impact, and the resulting shock impact should be less. Also, Cusimano et al.'s study (2011) supports this prediction.

2. Materials and Methods

Materials used for this experiment were as follows: Neewer Pro Photography Studio Kit: 7.8ft/2.4M, 2 sand bags, HAIREALM Head Bald Mannequin Head, vibrometer App, CAP Barbell 10 -Pounds Kettlebell, 49-strand Cable Vinyl Coated 7x7 Stainless Steel Kit 30 ft 275lb, 1.2mm W/10 1.4mm Crimps, Carabiners, iPhone 12s. Three types of helmets that were compared were Reebok 3k, Bauer IMS 11.0, Bauer IMS 5.0, and Nike Bauer NBH1500S. Two of these had a cage (Reebok and Bauer 5.0). A more detailed description of these helmets is in Table 1.

Table 1. The Description of Four Different Helmets Tested in The Experiment

Helmet Brand/Name	Cage or No Cage	Shell/Interior Padding
Reebok 3k	Has Cage	Aerodynamic Shell
Bauer IMS 11.0	No Cage	High-density polyethylene
Bauer IMS 5.0	Has Cage	Dual-Density Foam
Nike Bauer NBH1500S	No Cage	VN Foam

2.1 Procedure

This experiment was done in the backyard of a house with a balcony on the second floor (See Figure 1). The helmets were placed on the mannequin's head in the backyard, 20 feet away from the edge of the balcony. A cable from the balcony was attached to the fence behind the mannequin to create tension. A kettlebell was placed on the

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cable and a rope was attached to pull the kettlebell back to the balcony. Right in front of the fence was the mannequin attached to the tripod, which was secured by three sandbags which was 50 pounds.

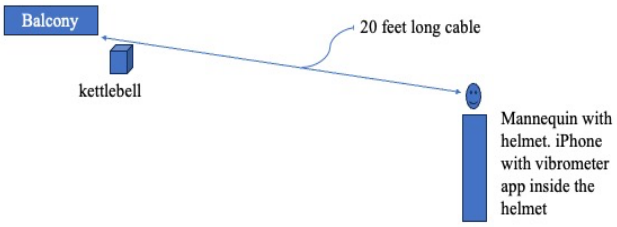

Figure 1: Illustration of the experimental set-up

Next, the experimenter made the beginning part of the rope go through the 10-pound kettlebell. When ready, the research assistant released the kettlebell from the balcony, and it started to slide across the rope. It finally hit the helmet on the mannequin within seconds.

The shock impact was measured by the Vibrometer App by ExaMobile SA (www.examobile.com) on an iphone 12s. This app measures the strength of the vibrations (i.e., acceleration) of the body or object. Acceleration is the change in velocity or speed per time interval. The meter per second squared (m/s^2) is the unit of acceleration in the International System of Units (SI). As a derived unit, it is composed from the SI base units of length, the meter, and time, the second. The iphone was placed inside the helmet, by the left ear of the mannequin, on the opposite side of the impact. After the kettlebell hit the helmet on the mannequin's head, the experimenter looked at the iphone, recorded the shock impact on my notebook and took a screenshot. The experimenter repeated this procedure 4 times per helmet (16 trials) and 4 times with no helmet (20 trials in total).

3. Results

The results are shown in Table 2 below. There were 4 trials per helmet, and 4 trials with no helmet (20 trials in total). The experimenter took an average of 4 trials per helmet. The average shock impact for helmet Reebok 3k was 12.8 m/s^2, for helmet Bauer IMS 11.0 was 17.6 m/s^2, for Nike Bauer NBH1500S was 16.0 m/s^2, and for helmet Bauer IMS 5.0 was 11.6 m/s^2. The average shock impact was 21.2 m/s^2 when there was no helmet. Therefore, the average for helmets with a cage (Bauer IMS 5.0 and Reebok 3k) was 12.2 m/s^2, whereas the average for the helmets without a cage (Bauer IMS 11.0 and Nike Bauer NBH1500S) was 16.8 m/s^2.

Table 2. The shock impact factor for each trial.

Helmet Type	Trial 1 (m/s^2)	Trial 2 (m/s^2)	Trial 3 (m/s^2)	Trial 4 (m/s^2)	Average (m/s^2)
Reebok 3k	12.6	13.1	12.8	12.5	12.8
Bauer IMS 11.0	17.9	17.5	17.8	17.0	17.6
Nike Bauer NBH1500S	15.6	16.9	15.2	16.3	16.0
Bauer IMS 5.0	11.3	11.3	11.7	12.2	11.6
No Helmet	23	21.8	19.8	20.1	21.2

A statistical analysis using SPSS (Statistical Package for Social Sciences V.23) was run. Specifically, a One-way ANOVA was run to compare the 4 types of helmets. The results showed that Reebok 3k and Bauer IMS 5.0 had less shock impact than the other two helmets ($F(4,15) = 63.2$, $p<.001$, effect size eta-square = .94) (See Table 3). Since the p-value (i.e., the level of statistical significance) was below the threshold of significance (typically $p < 0.05$), therefore the null hypothesis was rejected, the alternative hypothesis was supported.

Table 3. Summary of the ANOVA analysis

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	180.577	4	45.144	63.198	.000
Within Groups	10.715	15	.714		
Total	191.292	19			

When the average value of helmets with cage (12.2 m/s^2) and without cage (16.8 m/s^2) were compared using a t-test, the results showed that the shock impact was less with helmets with cage ($t(14) = 8.37$, $p<.001$). Additionally, t-test analysis showed that Reebok 3k with cage had more shock impact than Bauer IMS 5.0 with cage ($t(14) = 7.44$, $p < .05$). These results provided support for both hypotheses.

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4. Discussion

It was concluded that helmets with a cage resulted in less shock impact than helmets without a cage. Therefore, a cage is an important prevention gear in ice hockey. Out of the 4 helmets, Reebok 3k and Bauer IMS 5.0 (caged helmets) were the most effective in absorbing the shock. Furthermore, as predicted, Bauer IMS 5.0 was shown to be more effective in protecting from shock impact. It is suggested that youth ice hockey players should use caged helmets that are manufactured by Bauer.

There are some limitations in this experiment. First, tension on the cable may not always be the same. In future experiments, tension on the cable should be tested to ensure equal tension in each trial. Second, the force from the kettlebell may be less than the force in an ice hockey game. Therefore, in future experiments, forces that mimic reality can be used. A higher number of trials would improve the strength of this experiment. Additionally, different measurement devices should be used to test the shock impact in comparison to Vibrometer to test its validity. Finally, future studies should test the validity of the results by examining the variety of helmets and diverse playing conditions.

The results of this experiment have important implications. First, it is recommended that ice-hockey athletes should wear caged helmets to reduce injury. Second, Reebok 3k and Bauer IMS 5.0 brands are preferrable.

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CRISPR is an Incredible Tool for Treating Cancer

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Abstract

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) is a relatively new gene editing technology. It can be used in many ways, including cancer research and treatment. CRISPR and CRISPR associated enzymes (Cas) were discovered as an adaptive immune system in bacteria in 2013, and have already been used in clinical trials. In treatment, it binds to or removes mutated genes, canceling their effects. In research, this is used to test the necessity of the gene for cell survival or drug sensitivity. There are still several difficulties in using it, but it is already far better than previous tools, and will become better as research continues.

Keywords: CRISPR-Cas9, Cancer, Biotechnology, Gene editing

1. Introduction

The relatively recent discovery of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) has given researchers an incredible new way to treat and study cancer. Cancer is a disease characterized by genome instability and mutations that contribute to rapid cell growth. Researchers have attempted to treat cancer using genome editing for many years, but CRISPR appears to be the most successful. Many researchers have contributed to discovering and adapting CRISPR as a cancer treatment, especially Dr. Doudna and Dr. Charpentier, who were awarded the Nobel Prize in Chemistry for their work on CRISPR. CRISPR-Cas has been adapted for two main uses in cancer: as a key tool in gene therapy and as an invaluable research tool. In gene therapy, Cas, most commonly a version called Cas9, can function in numerous ways to edit the genome. For instance, it can remove the mutated gene, bind to the gene so it is inaccessible, and more. CRISPR screens are a research tool for testing how important a gene is to a cell's survival or to its sensitivity to a cancer drug. Researchers have worked hard to make CRISPR as reliable as possible, but more work is needed on the delivery of CRISPR, to make it a useful widespread treatment tool.

2. History of CRISPR as a gene editing technology

The history of gene editing begins with the discovery of the DNA double helix in 1953, and has exponentially progressed since then. CRISPR was first discovered in 1987 in *E. coli* bacteria by Ishino et al., but it was not investigated until the early 2000s (Doudna et al., 2014). Zinc-finger nucleases (ZFNs) were the first targetable gene editors, first used by Kim et al. in 1996. While they were useful, and certainly set the ball rolling for future gene editing, they were difficult to work with. Because of how they are programmed, the use of ZFNs is time-consuming and expensive. (Chandrasegaran, 2017) Their successors, transcription activator-like effector nucleases (TALENS) were much easier to use. TALs were first described in 2009 (Boch et al., 2009), and in 2015, were used as the first genomic treatment of cancer in humans (Qasim et al., 2017). CRISPR-Cas9 and other variants quickly became the most effective gene editing technique, beginning in 2011, due to the discovery of a second RNA strand essential to

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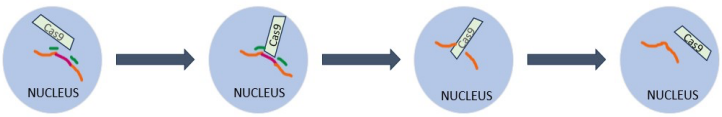
creating an *in vitro* CRISPR-Cas9 system by Charpentier et al (Charpentier et al., 2011). In January 2013, five articles were published saying that CRISPR-Cas9 had successfully been used to edit the genome of a human cell.

3. Mechanism of CRISPR

CRISPR has several enzymes associated with it that are necessary to its function. There is the Cas protein, an endonuclease, which actually binds and cuts the DNA, and there is the guide RNAs (gRNAs). A gRNA is a short RNA sequence which defines the genomic target as the DNA that will be complementary to their sequence. Cas9 - the enzyme variant most commonly used in cancer treatment - uses that to bind to where it needs to cut. Cas9 is used in relation to cancer more commonly than other variations because it is a type II system. Type II systems require one protein to function, whereas other types may require multiple proteins, making them much larger. (Brouns et al., 2008).

4. CRISPR is an incredible cancer research and gene therapy tool



= gRNA
= target DNA
= surrounding DNA

Gene name	Associated with:
TP53	Most cancers
BRCA1/BRCA2	Breast, ovarian, prostate, pancreatic
CHEK2	Breast, colon, prostate
PIK3CA	Breast, ovarian, brain, lung, stomach
ERK1	Breast, hepatocellular, lung, colorectal

Figure 1. CRISPR-Cas9 system can be used to edit genes associated with cancer. Colored lines represent DNA and gRNA. The green line represents the gRNA, which is complementary to the red target DNA. A simplified model is shown for clarity. The table represents a few common genes associated with cancer that the red DNA could represent.

In cancer treatment, CRISPR can be used to directly remove genes, replace genes, and enhance or repress the transcription of genes. The gRNAs can be used to direct the Cas enzyme to the target gene, where it will cut through the DNA. As it is stitched back together, there will be a few nucleotides either removed or added, so that the undesired gene can no longer be transcripted (Chiruvella et al., 2013). This is the most common way of forming breaks, called non-homologous end joining (NHEJ). It is also possible to fix breaks by adding a new gene, called homology-directed repair (HDR). Although it is not as common, as it is mostly limited to certain phases in dividing cells, it is more precise and less error-prone than NHEJ (Ran et al., 2013)

Deactivated Cas (dCas9) paired with transcription repressor can bind to and inhibit a gene's transcription. This inhibition is called CRISPR interference (CRISPRi). CRISPRi is valuable because preventing the transcription of a gene can reduce the effects of that gene's expression. This can be better than simply removing a gene for various reasons. It can potentially remove some off target effects of completely cutting the genome. It can also block more than one gene at a time (Yao et al., 2015). One benefit of CRISPRi as opposed to knockout treatment is that knockout completely removes the gene, restructuring the genome. With CRISPRi, the genome is still intact, but transcription of the target gene is inhibited. The effects of CRISPRi are also reversible, so it doesn't have to be a permanent change.

CRISPR activation (CRISPRa) uses dCas9 paired with an activation effector to enhance the transcription of target genes (Wang et al., 2022). It is essentially the opposite of CRISPRi. Where CRISPRi is used if the gene is being overexpressed or having negative effects on the cell, CRISPRa is used if a gene is being underexpressed or another gene is inhibiting its expression.

CRISPR screens are a powerful research tool. gRNAs are transduced into Cas9 or dCas9 expressing cells, at a low rate to ensure that there is only one gRNA per cell. With only one gRNA per cell, this ensures only one gene is knocked out per cell (He, 2021). Some cells will then be treated with a drug, while others are left alone as a baseline. After a set amount of time, the remaining cells will be sequenced, which can lead to a better understanding of what genes are responsible for certain things (Aguirre et al., 2016). For example, if a cell survives that has a gene knocked out in the untreated condition, that means the gene that was knocked out is irrelevant to survival or actually inhibits survival. If a cell does not survive that has a gene knocked out, then that gene was required for survival.

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Some screens also compare the baseline to what happens if the cell is treated with a drug (Bock et al., 2022). If, when treated with a drug, the cell survives, the gene that was knocked out was probably responsible for sensitivity. This can be checked against what happened without the drug. The opposite is also true. If, when treated with a drug, the cell dies, the gene that was knocked out was responsible for resistance. This is important because it allows for patient-centric, personalized therapy and maximizes efficiency in all therapies.

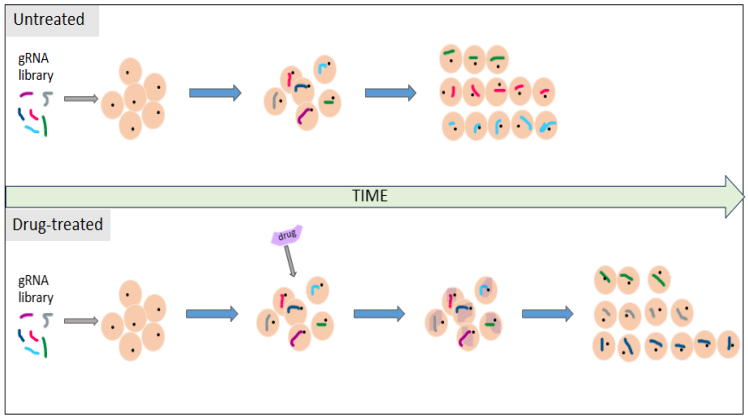

Figure 2. CRISPR screens are a research tool for studying genes that are critical to cancer progression or suppression. The dot in each cell represents Cas9, already integrated into the cell. Different gRNAs are represented by different colored lines. In the untreated panel, colors represented in the end show that the removal of those genes did not affect the survival of the cell. Colors that are not represented in the end represent genes that affect a cell's survival. In the drug-treated panel, colors represented in the end represent genes that contribute to sensitivity to the drug, as losing those genes causes those cells to survive more. Colors not represented in the end represent genes that contribute to resistance, as losing these genes causes those cells to survive less.

5. Difficulties in using CRISPR *in vivo*

There are two major difficulties in using CRISPR. One is the method of delivery. CRISPR is a large protein, so finding a carrier able to transport it is difficult. There are several methods, however, categorized into two major groups - viruses and nonviral. Viral methods can be divided into adenoviruses (AV), adeno-associated viruses (AAV), and lentiviruses (LV). Each method has its advantages and disadvantages. AAV are a fairly reliable method of delivery, especially *in vivo*, but they have a low cloning factor (Yang et al., 2016). AVs can transduce into any cells, and are widely used in clinical trials, but they are more likely to trigger an immune response that will prevent the AV from reaching its destination (Lee et al., 2017). LVs have a larger cloning capacity and can efficiently transduce into dividing and non-dividing cells. However, they have a tendency to randomly integrate with the genome, creating harmful mutations (Yip, 2020). There are several physical delivery methods, but these are impractical for *in vivo* delivery (Fajrial et al., 2020).

The other major difficulty is off target effects. These are things that may happen with the genome that are not on or near the target of the Cas9 protein. This can be a huge problem, as it could cause other difficulties for the cell or organism. The causes of target effects are not well understood, and neither are the actual effects.

There are ethical difficulties to using CRISPR as well. There are side effects of gene therapy that can drastically change a person's life, and researchers and doctors must consider what are acceptable consequences. They must also be careful of ethical laws, such as those against human experimentation (Gostimskaya, 2022). As CRISPR becomes more common, discussions of the ethics surrounding its use will become more important.

6. CRISPR now

Researchers have made enormous progress in utilizing CRISPR as a genetic tool. It will be extremely valuable if it can be widely used on patients, and will hopefully help with many genetic diseases and disorders. It has progressed incredibly quickly towards that point in only a decade. In 2013, its potential as a genetic tool was realized. Now, in 2023, there are many clinical trials for patients with cancer, some of which have been going on for years. Many genes associated with cancer have been identified, which is extremely useful for researchers (Gonzalez-Salinas et al., 2022). CRISPR can be targeted at these genes to remove or edit them, and can be used to identify drugs that can be used against cancer. Off-target effects and delivery methods continue to be a problem, but researchers are finding ways to avoid these difficulties. If researchers continue their studies and work to overcome the current challenges, both scientific and ethical, it may be possible to have a reliable cure to cancer with minimal effects, something that has only been dreamed of before.

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